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**SHORT TERM HEARING LOSS
IN GENERAL AVIATION OPERATIONS**

Phase I

September 1972

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Prepared under Contract NASW-2265

by

**BioTechnology, Inc.
Falls Church, Virginia**

for

**Aeronautical Life Services Division
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION**

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Foreword

This report is the first part of a two-part final report prepared by BioTechnology, Inc. under Contract NASW-2265 with the National Aeronautics and Space Administration. The work was performed under the direction of the Aeronautical Life Sciences Division with Mr. Raymond P. Whitten serving as Project Monitor. Mr. Whitten's help during the conduct of the study is gratefully acknowledged. An earlier version of Phase I report was submitted by Mr. Whitten in partial satisfaction of the requirements for the degree of Master of Arts, The Graduate School of Arts and Sciences, The George Washington University.

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Introduction

In his usual living and working environment, man is subjected to sounds that may have injurious properties. These properties are normally defined in terms of sound pressure levels and frequency spectra. The energy and frequency characteristics of these injurious sounds can induce permanent damage to hearing by destroying or altering the sensory cells of the organ of Corti within the cochlea. A sensorineural type of hearing loss thus can be caused by exposure to noise. Loud noises can also alter the cochlear structure. Exposure to certain noises may lead to a loss in hearing which will appear as a shift in the hearing threshold. If the exposure is of short duration, the loss is usually temporary (TTS) with partial or complete recovery in minutes, hours or days. However, the effects of noise are cumulative; and if these temporary threshold shifts continue on a day-to-day basis, a permanent hearing loss (PTS) will result (Newby, 1958).

The cause of threshold shift is often ascribed to fatigue of the hair cells within the cochlea. This fatigue has been described as a complex deteriorative change that is ordinarily reversible, i. e., overcome by adequate rest and change of activity. However, irreversible organic damage or severe mental disturbance can occur in extreme cases (Bills, 1963). The extent of auditory fatigue is related to the duration, intensity and frequency of the stimulus.

Because long-duration exposure to noises that produce auditory fatigue may entail a risk of permanent damage to hearing, criteria have been developed which establish noise tolerances. The criteria generally are expressed as damage risk contours. It has been common practice in the past to determine the auditory noxiousness of an environment solely by physical

measurements centered around sound pressure levels and frequency spectra. Findings of Botsford (1968), Eldridge and Miller (1969), Loeb and Fletcher (1963), Kryter (1965), Nixon and Glorig (1961), Ward et al. (1959), and Ward (1962, 1969) have paved the way to a new and perhaps better approach for damage risk assessment, the psychophysiological measurement and interpretation of threshold shifts.

Noise-Induced Hearing Problems

The parameters of the human auditory system's response to acoustic stimuli have been broadly categorized by Ades (1959) into three ranges of frequencies. The sonic range is derived from the upper and lower perceptual limits of the young adults' ear. Frequencies below the sonic range (i.e., below 20 Hz) are called infrasonics (16,000 to 20,000 Hz), while frequencies beyond human perception are called ultrasonics. Since the sonic perceptual range is an arbitrary one, established by statistical averages of behavioral responses to sound, an individual's performance often varies from the population average. According to Tolhurst (1969), the statistical ear is: (1) non-linear at the intensity levels required for detection of a sound; (2) most sensitive in the frequency region of one octave above and below 1500 Hz; (3) highly resilient to wide-intensity changes; and (4) perceptually distorted at approximately 120 dB, becoming intolerably pained around 150 to 155 dB SPL.

According to Glorig (1963b), the temporary elevation of auditory threshold which results from one day of exposure to noise levels of 100 dB or more may vary from no shift to 40 dB. Exposure to typical industrial noise produces the largest temporary loss at 4000 and 6000 Hz. The major portion of this loss occurs during the first one or two hours of exposure. The amount of temporary loss is roughly the same for the same person from day to day, but varies from person to person according to a normal statistical distribution.

The amount of temporary loss and its frequency location vary with the amount and frequency location of permanent loss; the more permanent loss at any frequency, the less the temporary loss at that frequency. Finally, recovery from temporary or transient hearing loss occurs mostly within the first hour or two after the noise exposure has ended.

Permanent Noise-Induced Threshold Shift (PNITS) is normally produced by long-term exposure to intense noise, presumably as a result of inner-ear damage. Serial audiograms of persons exposed to intense noise reveal a progressive hearing loss. The loss usually appears first at frequencies between 3000 Hz and 6000 Hz, then, in time, spreads in both directions until hearing for most of the audible frequencies is affected. The amount of noise exposure experienced determines the extent of the spread.

Permanent noise-induced hearing loss is usually a slow, insidious process wherein years of exposure may elapse before a significant loss of hearing occurs (Figure 1).

Hearing loss varies with the type of exposure, intermittency, and total duration of exposure to noise (Glorig, 1963b). The degree of both temporary and permanent hearing loss for the same amount of noise exposure may vary greatly from one person to another (Cohen, 1963). In this regard, some effort has been directed toward developing a technique which will identify the noise-susceptible or "weak" ears.

Glorig (1963b) reported one criterion for long-term (more than five hours per day) habitual exposure based on studies of Noise-Induced Permanent Threshold Shifts. He noted that 80 dB SPL at 1200 to 2400 Hz will produce only a moderate shift of threshold at 4000 Hz over a period of ten years. After years of exposure to 84 dB SPL in the octave bands lying between 600 to 4800 Hz, there is only slightly more loss at 2000 Hz than is found in the general male population. Therefore, 85 dB SPL at 600 to 1200 Hz was chosen as a hearing

conservation criterion for long-term exposure to continuous steady, nonimpulsive noise. If the exposure time is less than five hours, and allows the ear to recover from the threshold shift, it is considered short term. If no more than 12 dB TTS at 2000 Hz accumulates during a work day, no significant NIPTS will occur during a work life (Glorig, 1961).

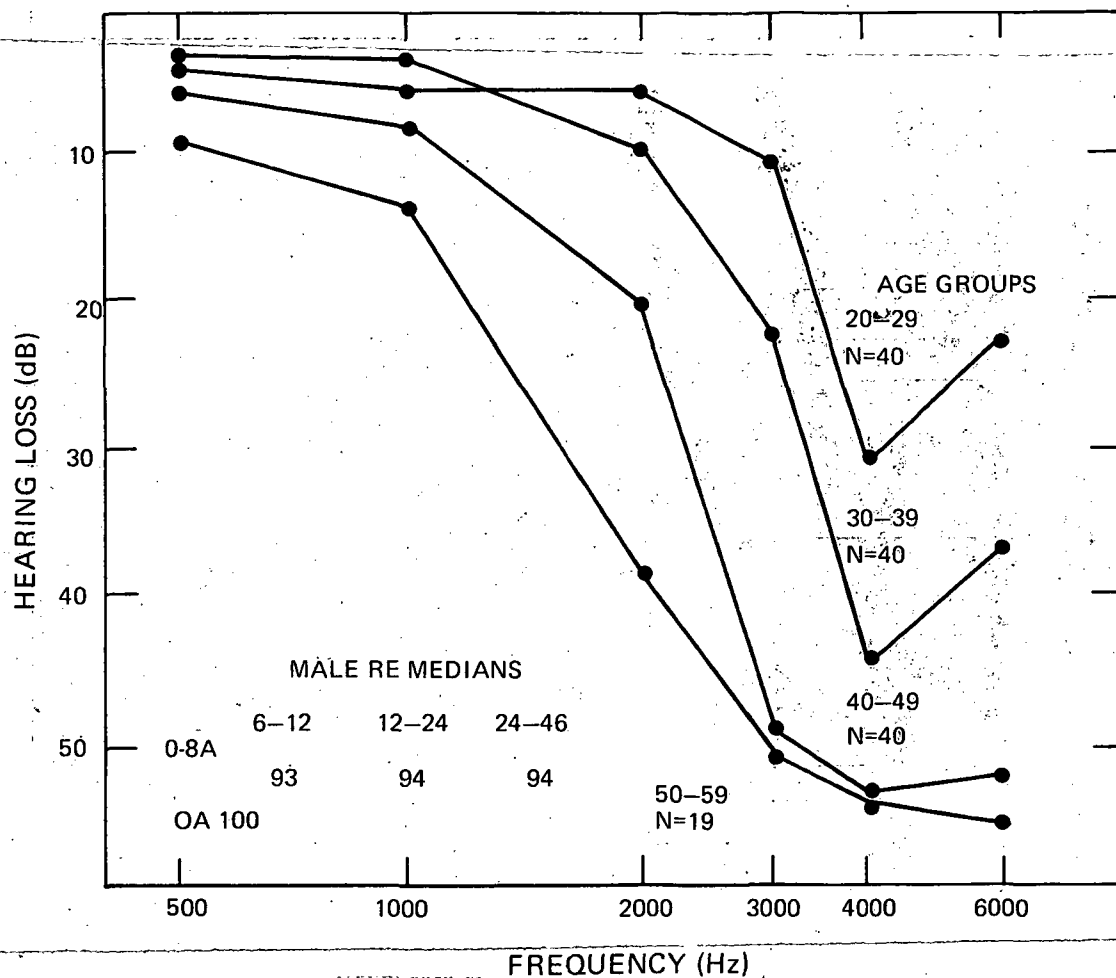
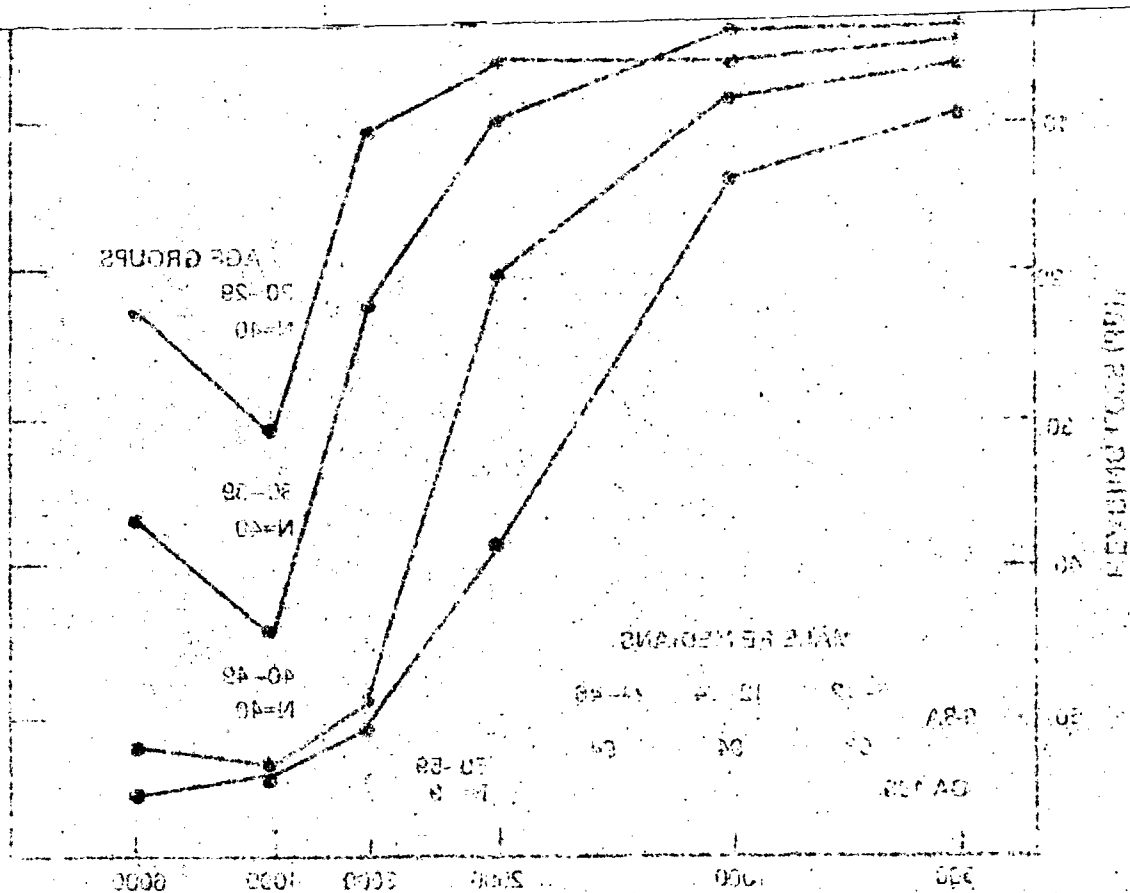


Figure 1. Noise-induced hearing loss as a function of age (from Glorig, 1963a).



Theory of Temporary Threshold Shift

The elasticity of the auditory system has been described by the human response measure known as Temporary Threshold Shift (Hood, 1950; Ward, 1962, 1969). This is the decibel difference in threshold of audibility measured before and after exposure to sound. If after a specified period of time, usually no longer than 24 hours, an individual's threshold returns to preexposure levels, the shift is considered temporary. Hood (1969) found that a 90 dB SPL tone gives a TTS of 30 dB after a three-minute exposure with almost complete recovery in 60 to 120 seconds. He further reported that the threshold shift increased with increased intensity of the tone at individually different rates.

Based on research findings which revealed a relationship between TTS after eight hours of noise exposure and PTS incurred using an eight-hour day over ten to twenty years of exposure to noise, Working Group No. 46 was formed by the NAS/NRC Committee on Hearing, Bioacoustics and Biomechanics (CHABA) to outline criteria for hazardous noise exposure. Figure 2 gives a summary of the general recommendations concerning intensity-time-octave bands of noise exposure which were based on the assumption of equivalence of the TTS index to a NIPTS resulting from long-term noise exposure. Hence, the damage risk criteria adopted by CHABA is a median TTS of no more than 10 dB for frequencies lower than 1000 Hz, 15 dB for 2000 Hz and 20 dB for frequencies higher than 3000 Hz. If adhered to, these criteria should ensure that 95 percent of the population incur no permanent hearing loss.

Noise exposure criteria for steady-state noise seem to have enough experimental validity to form the basis for a working hypothesis as to damaging intensity levels. Evidence showing the elasticity range of the ear to impulse noise is meager. Ward (1962) measured temporary threshold shifts at frequencies from 500 to 13,000 Hz and found that for fatiguing noises of interpulse intervals of one, three, and nine seconds, the TTS was essentially

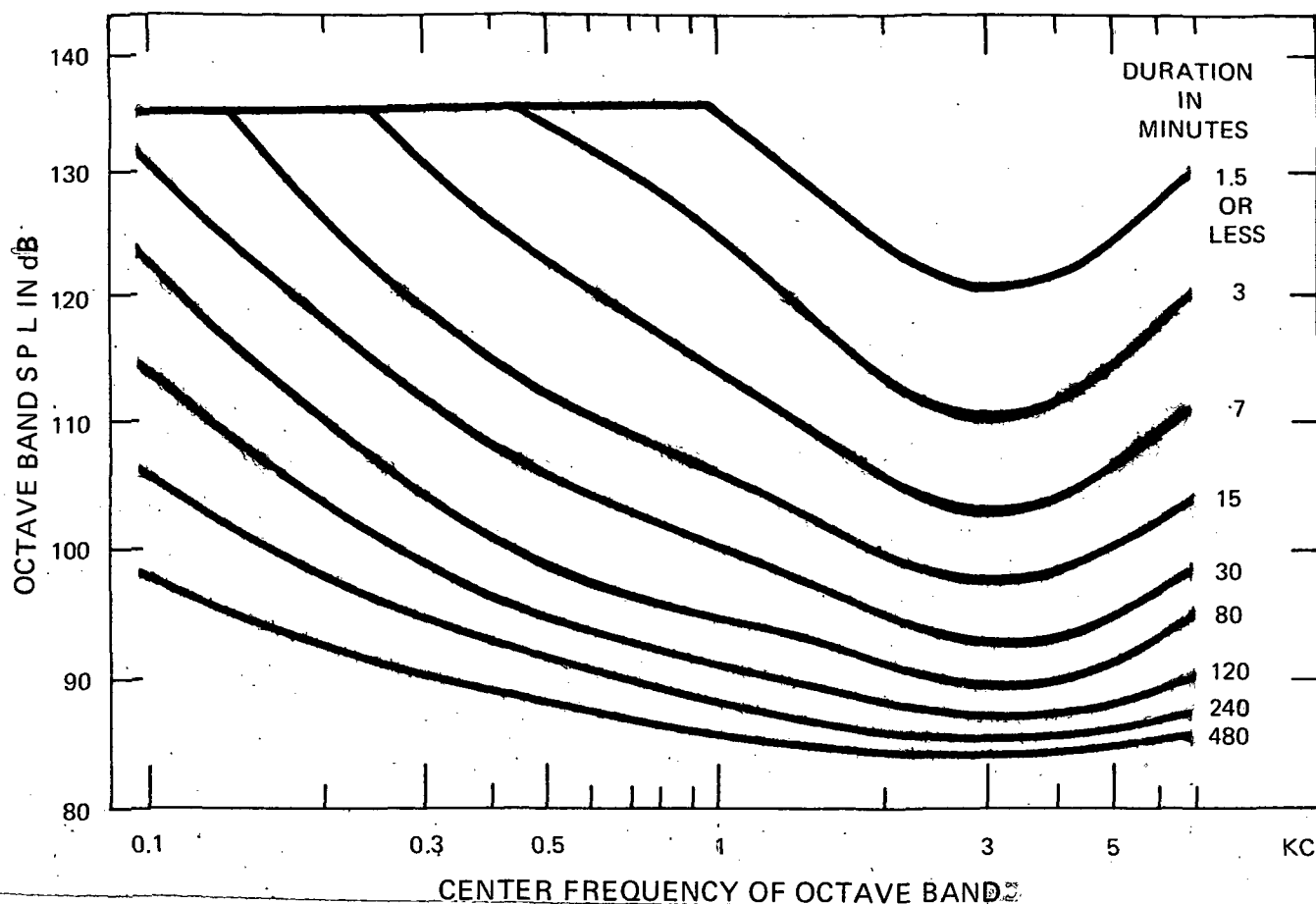
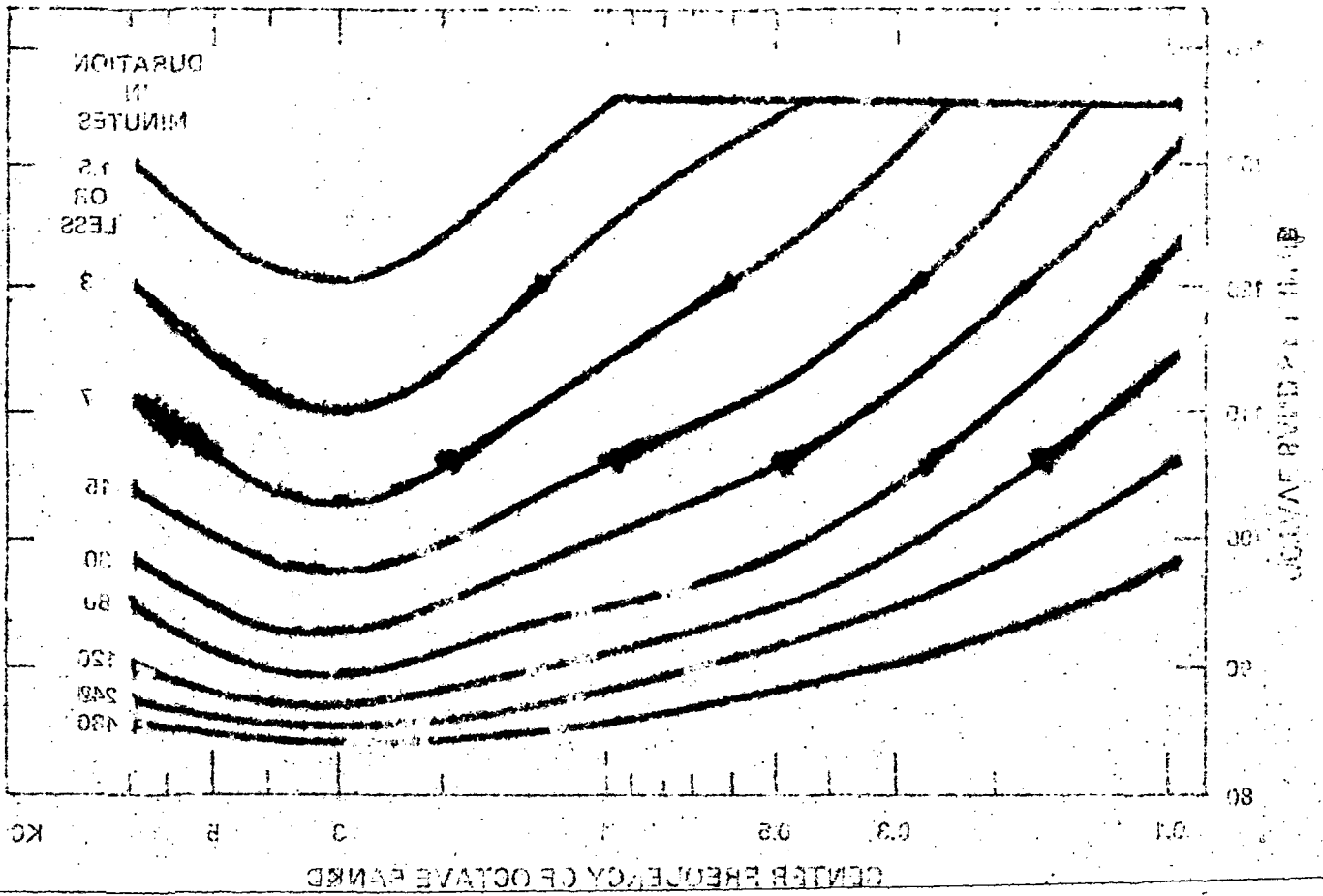


Figure 2. Damage risk criteria (Kryter, 1965).

equivalent. Less effect was found for noise at 30-second interpulse intervals, but TTS recovery after five minutes was almost the same as for the more rapid pulses.

The transition between a condition of TTS and PTS can be thought of as the point at which the elasticity range of the ear is exceeded and at which it enters a state of deformation.

Several hearing conservation recommendations use simpler parameters than those of CHABA Working Group No. 46. The U.S. Navy set 90 dBA as the maximum allowable eight-hour per day exposure to wide-band noise



Relationships

(BUMEDINST 6260.6B). Another criterion suggests 88 dBA as acceptable for wide-band noise and 95 dBA for narrow-band noise (Jansen, 1969).

Statement of the Problem

Sound waves of high intensity, especially in octave levels above 1000 Hz, can cause a TTS lasting several hours and, if persistent, an eventual PTS. Tobias (1968a, b) studied the cockpit noise levels of three crop-dusting aircraft and fifteen single-engine light aircraft during normal cruise at mean sea levels of 2000, 6000, and 10,000 feet. When these levels were compared to the damage risk curves established by Kryter et al. (1966), they were found to be potentially damaging to man's hearing. Later, Tobias (1968c) studied the noise intensity of eleven twin-engine light aircraft and found that the noise levels, although quieter than single-engine aircraft, could also endanger the human hearing mechanism. Stone (1967) reported similar findings in commercial passenger aircraft.

Although the levels of noise in various types of aircraft have been reported as potentially hazardous to the human hearing mechanism, no reports concerning actual threshold shift in passengers and pilots are to be found in the literature. Further, the extent of TTS caused by normal aircraft operations and its duration have not been explored.

The actual physical measurement of the environment is important and provides a good index for potential hearing problems. However, it is felt that use of TTS measurements along with predictability curves (damage risk contours) would provide more definitive determinations of the potential hazard of the operational noise of light aircraft. Noise-induced TTS can lead to: (1) physiological fatigue (Tobias, 1963); (2) hearing impairment-- when projected on man-hour exposure over several years (Botsford, 1969); and masking of speech, radio and weapon systems signals (Kryter, 1946; Tolhurst,

1969). Each of these factors can be deleterious to the safe operation of aircraft as well as a danger to hearing.

There are 114,344 piston type single-engine aircraft and 16,434 multi-engine piston type aircraft registered with the Federal Aviation Administration. A total of 729,900 pilots were licensed in 1971, and 127,004 new students were registered in 1970. During 1970, the total general aviation hours flown in all categories was 26,660,256. In view of the above facts, the objective of this research was to investigate the TTS experienced by passengers and pilots during preflight, flight, and postflight operations of a light aircraft.

It was the purpose of this study to: (1) analyze the type of noise produced by a light aircraft during various phases of flight; (2) measure the TTS induced by flight operations; and (3) discuss the findings in terms of any potential hazard in light aircraft operation. The findings of this study will be compared to existing contours for damage risk to hearing.

Throughout this report, certain terms are frequently employed. The following definitions may be helpful:

Preflight refers to those activities associated with normal air operations that are required to prepare the flight crew and aircraft for flight. Such activities normally involve flight planning, weather checks, filing the flight plan, inspection of the aircraft, taxi and engine run-up and check.

Flight includes all of the time during which the aircraft is aloft.

Postflight encompasses that time from touch down until the aircraft is secured and the flight properly logged.

Temporary threshold shift (TTS) indicates the difference in the threshold of hearing measured before and after exposure to flight operational noise.

Procedures

Table 1 outlines the experiment protocol. A test population of six subjects was used in this study. The subjects consisted of two females and four males ranging from 18 to 45 years of age. The investigator participated as a subject. Prior to participation in the study, each subject was given a short familiarization lecture explaining the scope of the project and baseline audiograms were taken. Four of the subjects exhibited hearing within normal limits in both ears (thresholds no greater than 10 dB at frequencies of 250 through 8000 Hz). Two of the subjects displayed sensorineural hearing losses. On the basis of air conduction and bone conduction thresholds, one was found to have a loss of 15 dB at 6000 and 8000 Hz in his left ear. The other subject displayed a loss of 25 dB at 6000 Hz and 15 dB at 8000 Hz in his right ear and his left ear exceeded the limitations of the audiometer at 6000 and 8000 Hz.

As indicated in Table 1, each of the subjects participated in three flights of approximately two, four, and six hours' duration. Audiograms were again determined immediately before and after flights.

Instrumentation

A Beltone 15C clinical audiometer with TDH 39 earphones was used to complete the reference audiogram. An Ambco Model 601-D portable audiometer was used in the field for the subsequent tests. The test environment for the field audiograms was an automobile parked in the vicinity of the airport, but removed from the general environment of the flight operations. In all cases, the pure-tone source was calibrated to the 1964 ISO norms.

A UHER 4000-L tape recorder was used to record all noise environments. The noise stimuli were fed to the tape recorder via a General Radio Sound Level Meter, type No. 1551-053. A preflight calibration tone was introduced by a General Radio Sound Level Calibrator, type 1562-A.

Table 1
Experimental Program

Preflight Measurement

General Indoctrination

Reference Audiogram

Field Audiogram

<u>Inflight Noise Exposure</u>	<u>Subjects</u>	<u>Total Flight Hours</u>
2 hours (Pretest of data collection system)	1	2
2 hours	4	8
4 hours	4	16
6 hours *	4	24
	Total	50

Postflight Measurement

Postflight Audiogram

* Required short refueling stop after three hours of exposure.

The noise levels, as recorded, were analyzed for intensity and frequency at the Noise Research Facility at the NASA Langley Research Center, Hampton, Virginia. A General Radio Sound Level Meter, type 1565-A was used to spot check noise levels during the investigation. These instruments conform to the USASI USA Standard Specification for General Purpose Sound Level Meters (SI. 4-1961) and IEC Recommendation R 123.

The aircraft used in this study was the Twin Engine Piper Apache (see Figure 3).

Audiograms

Standard audiometric procedures were used throughout this study. A reference audiogram was completed on each subject at the Audiology Clinic of the Federal Aviation Administration, Washington, D. C. Individual thresholds were obtained using the modified Hughson-Westlake technique suggested by Carhart and Jerger (1959). Air conduction thresholds were obtained for frequencies of 250, 500, 1000, 2000, 4000, 6000, and 8000 Hz. Bone conduction thresholds were obtained only on subjects exhibiting air conduction thresholds poorer than 10 dB (ISO 1964). Reference audiograms were completed only after a 48-hour period away from high-noise areas. This was done in order to prevent the influence of any existing TTS.

Prior to completing each field audiogram, the ambient noise level was measured in the test environment. At no time did the noise level exceed 44 dBA. The test frequencies used were 500, 1000, 2000, 3000, 4000, and 6000 Hz. These audiograms were made just prior to the subjects' exposure to preflight noise. Immediately following aircraft secure (within two to five minutes) a postflight audiogram was obtained in the same environment following the same procedures.

Figure 3. Piper Apache aircraft

Figure 3

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Apache 4389P



Pilot and Copilot Compartment



Rear Passenger Compartment

Calibration

Using a General Radio Sound Level Calibrator, type 1562-A, the tape was calibrated at 2000 Hz at 114 dB SPL. The tone was fed to the UHER Recorder through the General Radio Sound Level Meter which was calibrated to 114 dB SPL at a weighting level of 20,000 Hz. This allowed for complete spectrum analysis. The tape recorder was calibrated for - 12 dB SPL and operated at 7-1/2 ips for maximum fidelity.

Noise Spectrum

For each flight, two minutes of preflight noise was recorded. All recordings in the aircraft were made at the right and left ear position of the subjects. Noise levels during aircraft runway, taxi, takeoff, and climb to altitude were recorded. During the flight, 15 minutes of cruise noise were recorded, as well as noise levels for changes in cruise manifold pressure and RPM. Recordings were made during each landing (from initial airport approach), touchdown, taxi, and postflight noise levels. The tape from each flight was taken to the Langley Research Center for spectrum analysis. In-flight noise was monitored in order to note and record any large deviation in the ambient noise level.

Analysis

Spectrum analysis of the field audiometric test environment revealed that it was well within reasonable noise tolerance for threshold measurements. Although the overall noise level for the environment averaged 58 dB SPL, a much lower noise level was found for those frequencies used in audiometric testing (see Figure 4). Noise measurements were taken for all twelve flights; however, due to equipment failure only ten tapes were suitable for averaging the operating noise environment. To further lessen the effects of environmental noise on threshold testing, Rudmose otocups were used with the headphones on the pure-tone audiometer.

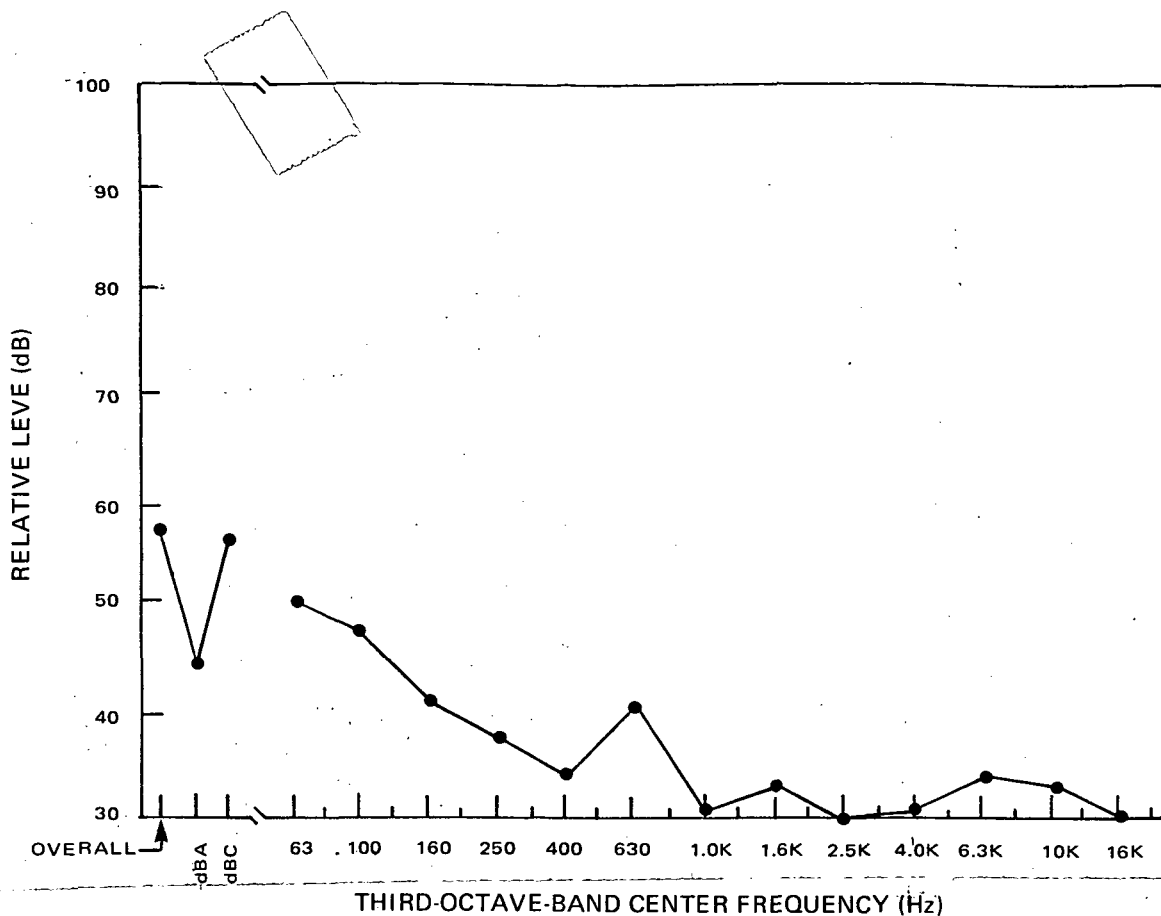


Figure 4. Average noise levels of field test environment.

Figure 5 shows the average noise levels taken in the position of the occupants during cruise time. The greatest concentration of sound energy occurred during the climb to altitude. However, this phase of the flight lasted, on the average, seven minutes. Since the longest exposure to noise occurred during cruise, these data were extracted and are presented in Table 2. As can be seen in the table, the largest concentration of energy during the cruise time is found in the octave bands below 1000 Hz.

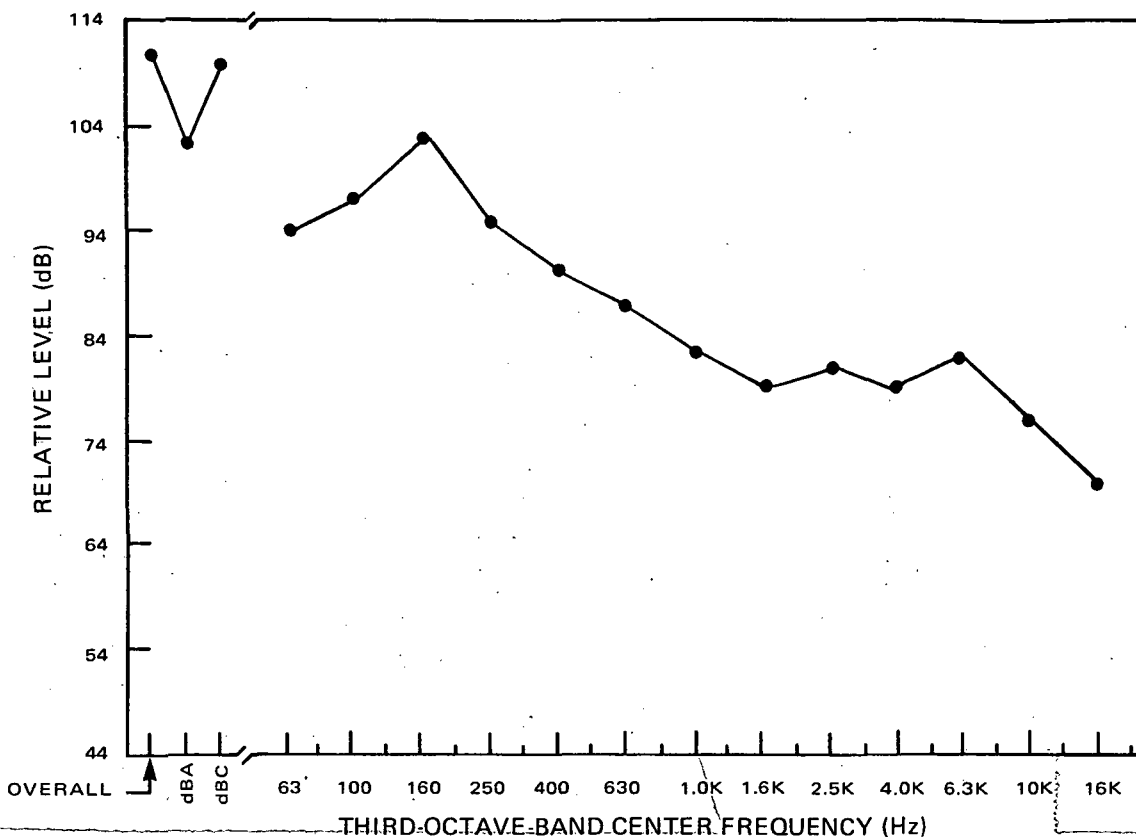


Figure 5. Average noise levels during cruise.

Results

The average threshold shift for all subjects during their three separate flights is presented in Figure 6. As shown in Figure 6, the most significant shifts occurred during the six-hour flights at frequencies of 500 and 6000 Hz. The greatest amount of shift was seen at all frequencies, except 3000 Hz, during the six-hour flights. At 3000 Hz, a greater shift was found after the four-hour flight. It is noteworthy that the least amount of shift routinely occurred at 2000 Hz. Figures 7, 8, and 9, which show the average threshold for each subject, indicate this clearly for all subjects except subject 1. The dotted lines found on these figures demonstrate the median values considered hazardous (Kryter, 1965).

Table 2
Mean Noise Levels During Cruise Time

<u>Reference</u>	<u>Right Ear</u>	<u>Left Ear</u>
Overall	111	110
dBA	98	96
dBC	110	110
63 H63 Hz	94 dB	94 dB
100	97	101
160	103	102
250	95	95
400	91	91
630	86	84
1,000	82	81
1,600	79	78
2,500	77	77
4,000	75	75
6,300	78	76
10,000	76	75
16,000	70	69

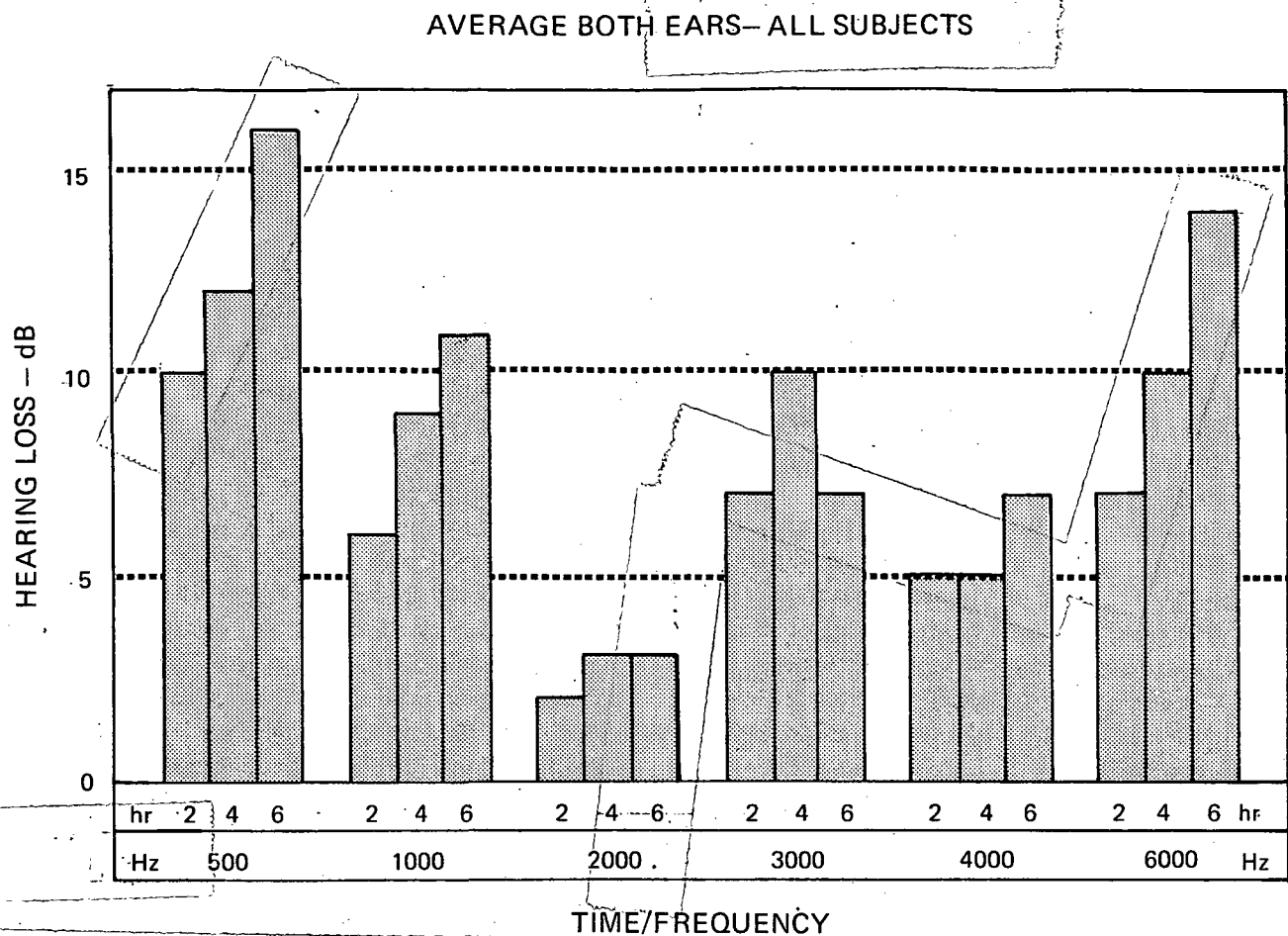


Figure 6. Average threshold shift for all subjects.

With the exception of one subject, No. 6, all of the subjects' thresholds returned to normal within one hour of the postflight audiogram. Subject 6 was an 18-year old Caucasian female whose baseline audiogram was normal. At the end of her first flight, she displayed a 10 dB threshold shift at 6000 Hz. This threshold did not return to normal by her next flight which was four months later. At the end of the second flight (four hours), she experienced an additional 12.5 dB shift. Three weeks later, the preflight audiogram for the six-hour flight revealed a persistent 20 dB loss at 6000 Hz. The post-flight audiogram showed an additional 12.5 dB loss at the end of that flight. Figure 9 shows that this subject experienced little threshold shift other than at 500 and 6000 Hz.

AVERAGE BOTH EARS – EACH SUBJECT

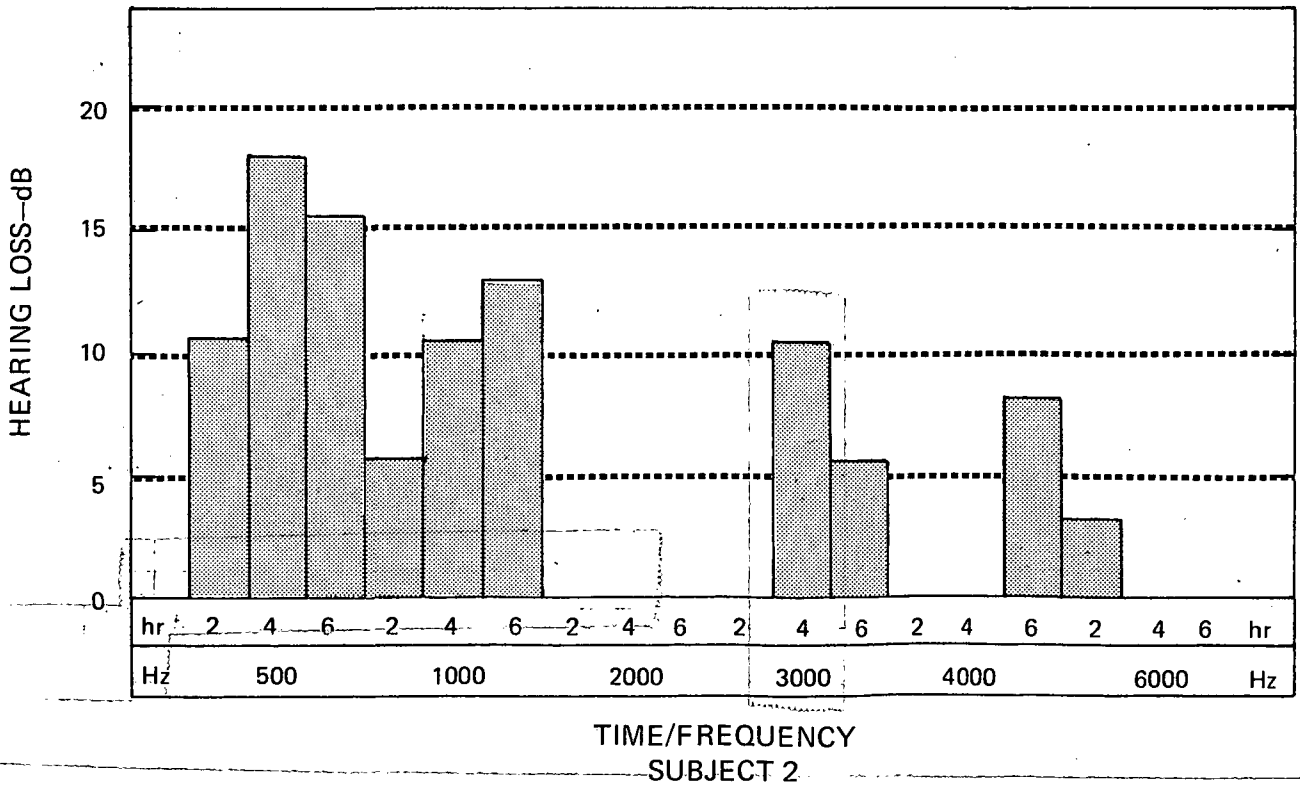
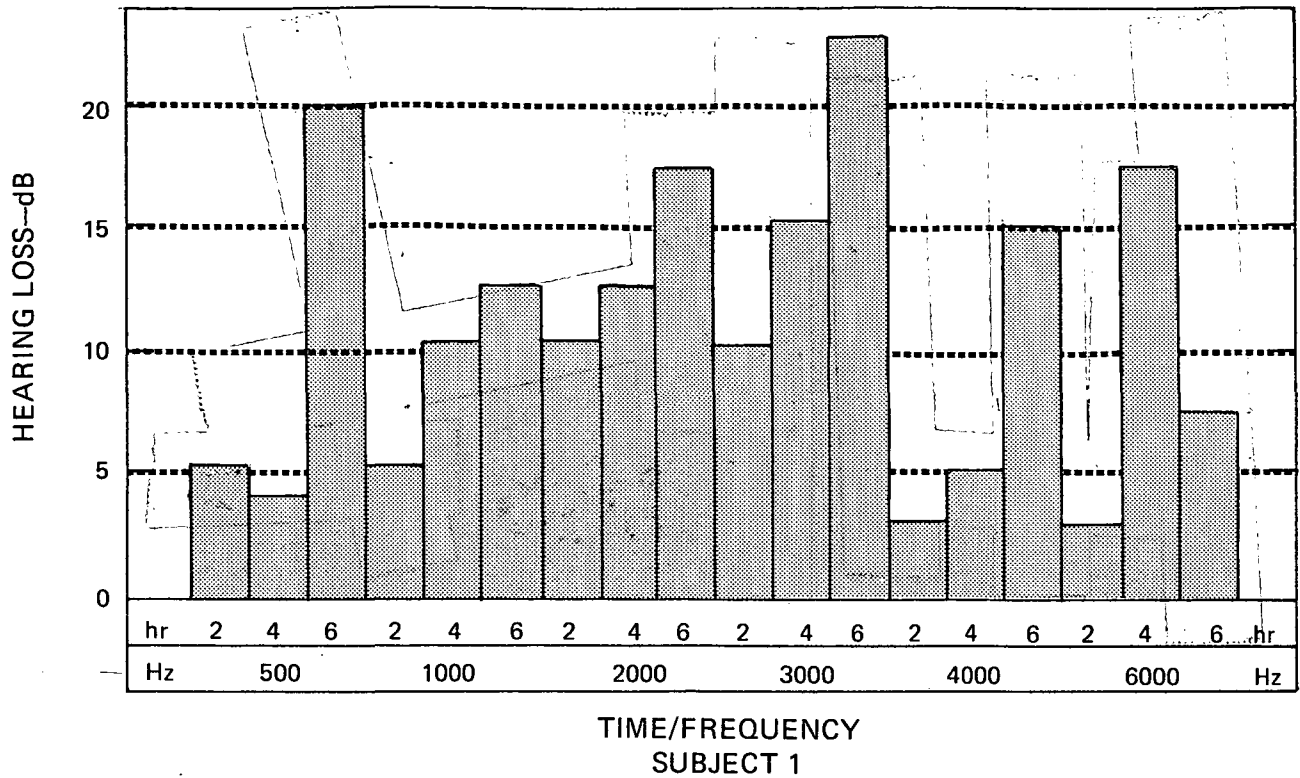


Figure 7. Average threshold shift for subjects 1 and 2.

AVERAGE BOTH EARS – EACH SUBJECT

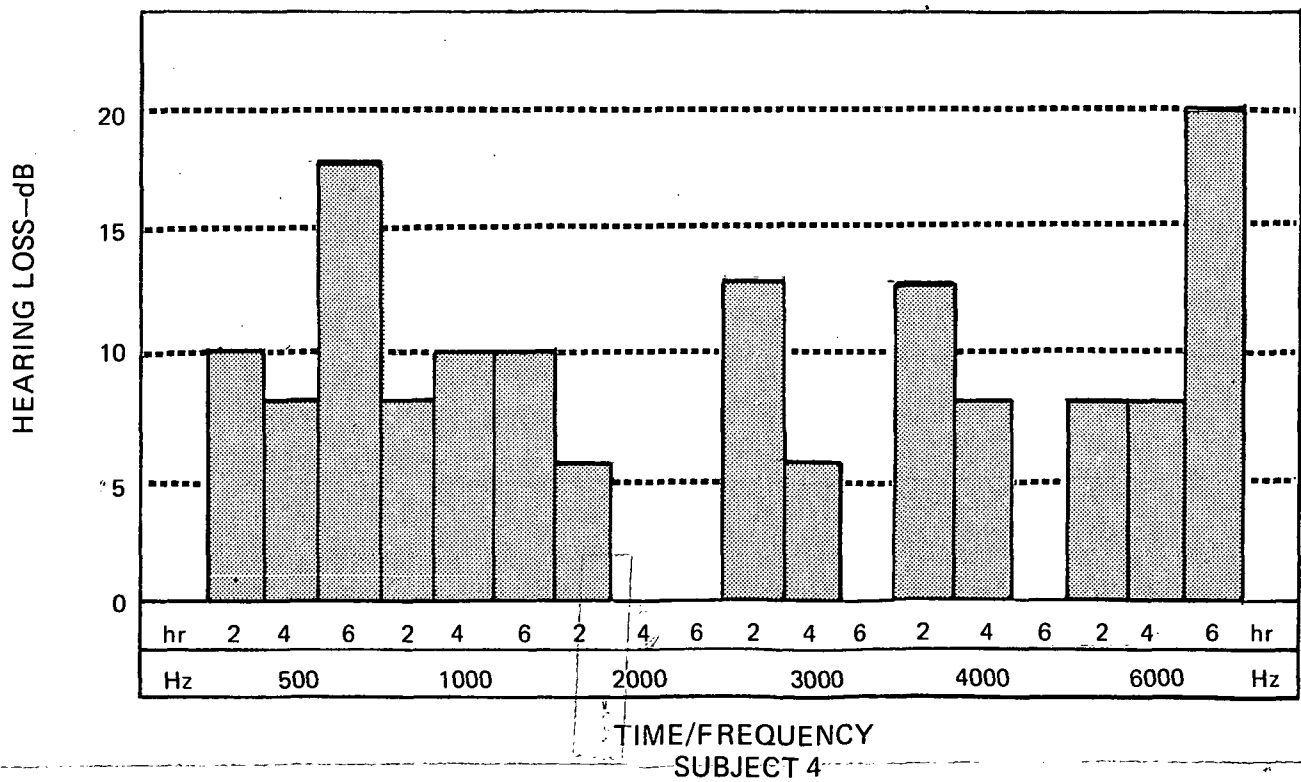
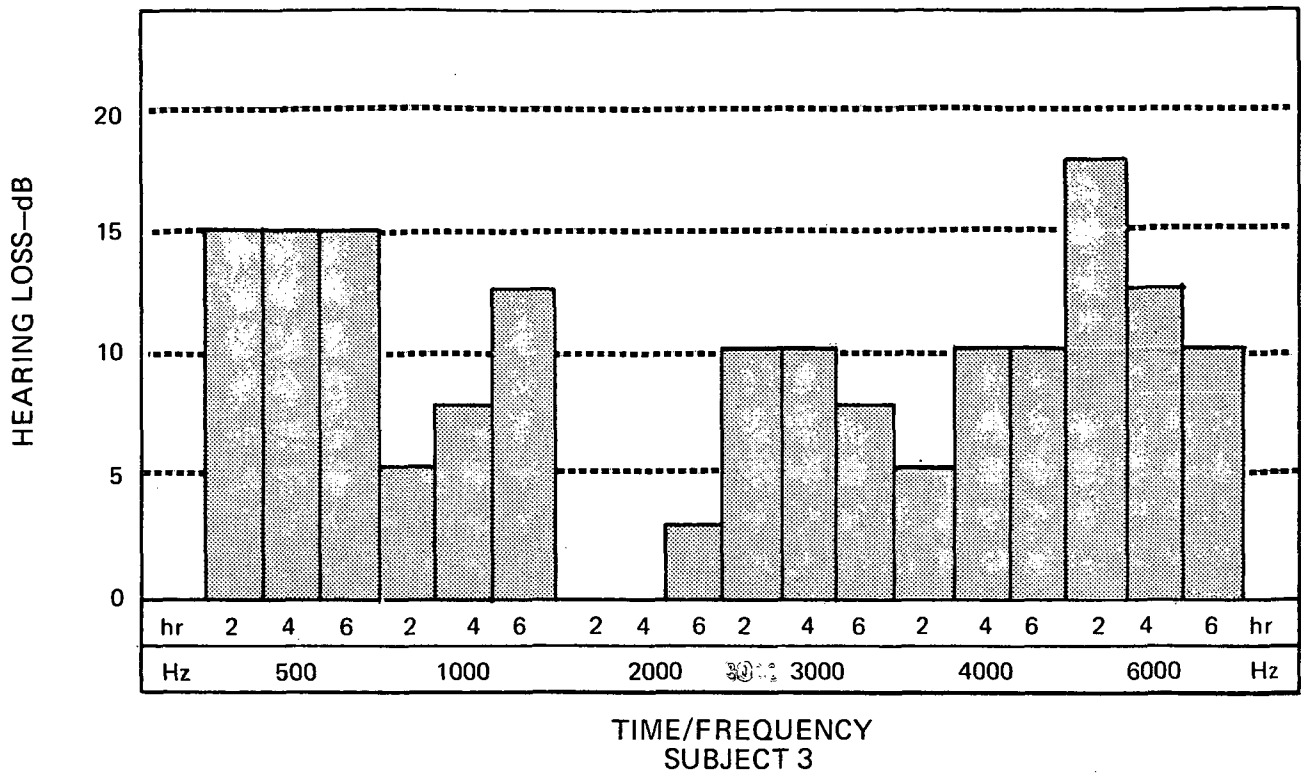


Figure 8. Average threshold shift for subjects 3 and 4.

AVERAGE BOTH EARS – EACH SUBJECT

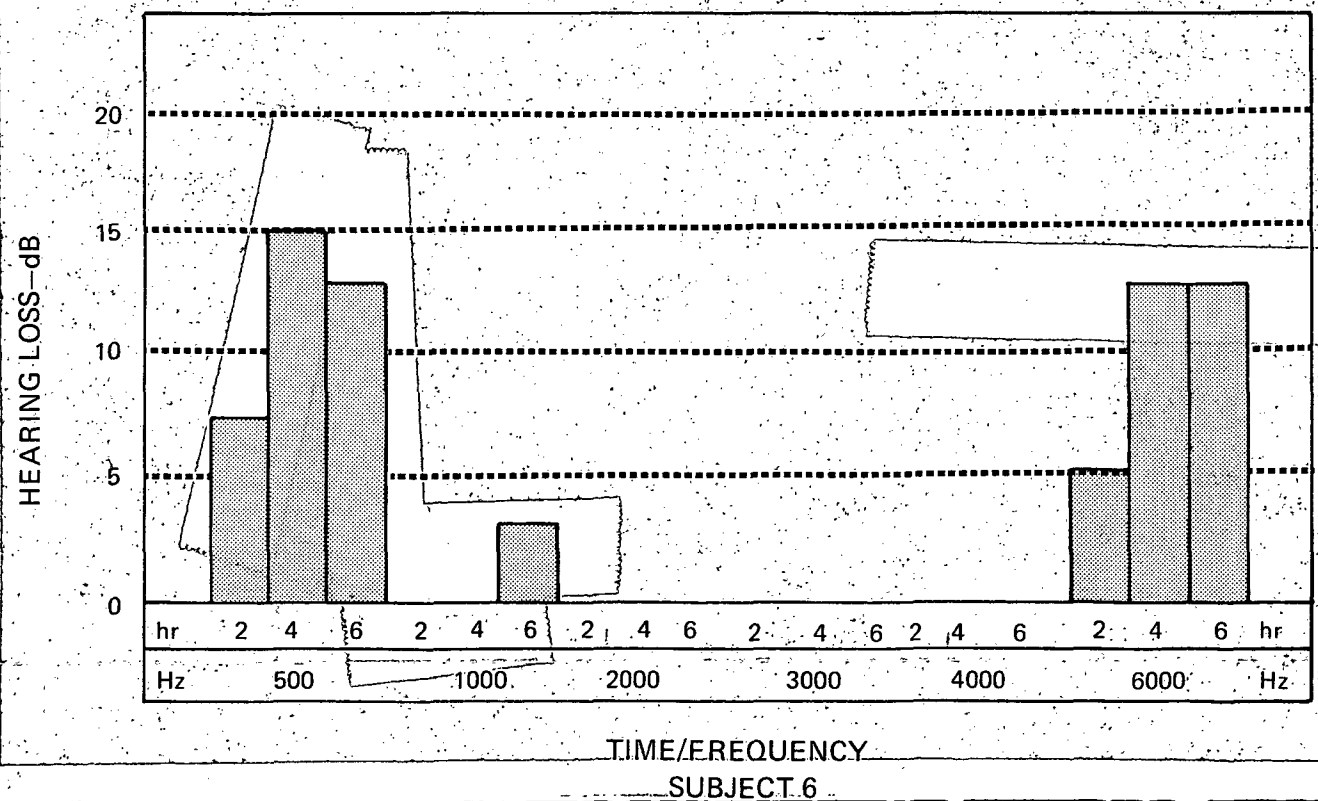
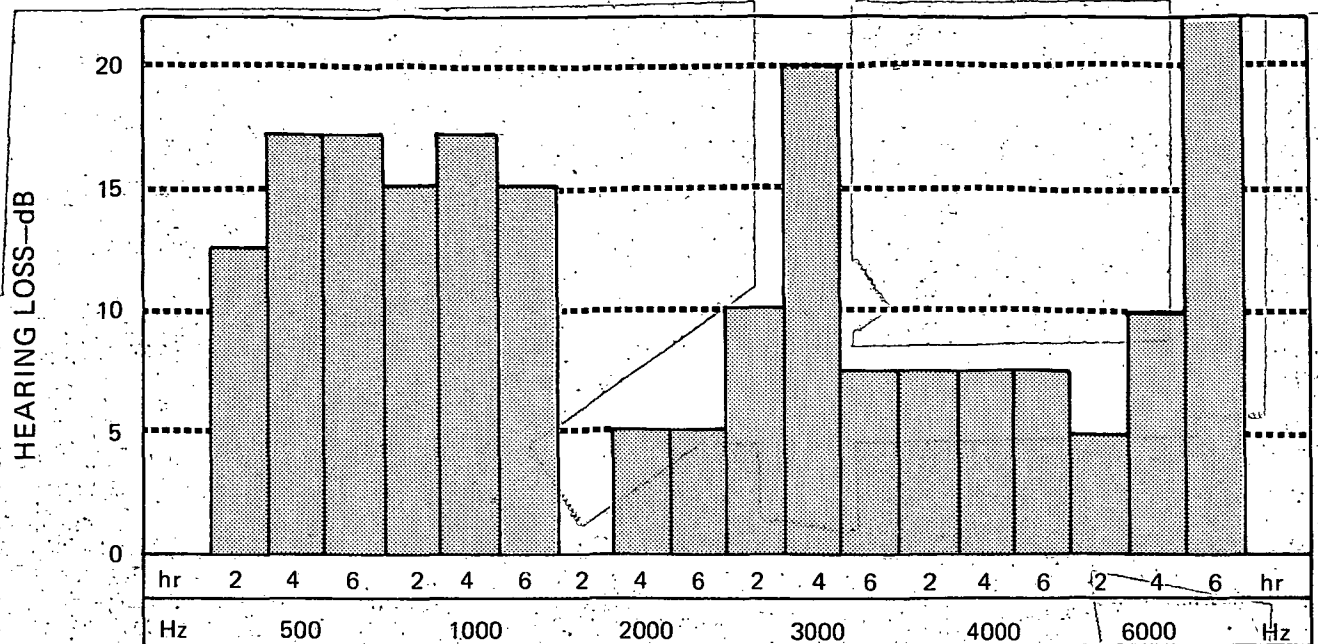


Figure 9. Average threshold shift for subjects 5 and 6.

Conclusions

The effects of light aircraft noise on six subjects during flight operations were investigated in this study. The noise environment in the Piper Apache light aircraft was found to be capable of producing hearing threshold shifts. The following are the principal findings and conclusions to be drawn from the data obtained in this investigation.

1. Through most of the frequency range for which measurements were taken (500 to 6000 Hz), there was a regular progression showing increased loss of auditory acuity as a function of increased exposure time. Thus, as one might expect, a six-hour flight produced a greater temporary threshold shift than did a two- or four-hour flight. This is of consequence inasmuch as many light aircraft now are capable of nonstop flights lasting from five to six hours.

2. Extensive variability was found in the results among subjects and in the measured loss at discrete frequencies for each subject. This variability is typical of the results of hearing loss from noise exposure. Part of it undoubtedly is a real result of differing neurological responses to overstimulation. Another part of it, however, must be attributed to the experimental error which is unavoidable when measurements are obtained under field conditions.

3. The principal loss of hearing found in this study occurred at the low frequencies, around 500 Hz. This may be attributed to the fact that the bulk of the acoustic energy provided by light aircraft engines is in the low frequency range, from 100 to 500 Hz. At higher frequencies (2000 to 3000 Hz), there was only a modest loss of auditory acuity. At a still higher frequency (6000 Hz), there was a greater loss of hearing. The reason for this U-shaped function, showing principal loss at both the lower and higher frequencies, is unknown.

Today, we are experiencing a burgeoning in the light aircraft industry and in the number of licensed pilots. This fact alone dictates that more information be gathered with regard to hazardous noise conditions in various types of light aircraft. The results of this study further suggest that more consideration be given to the effects of exposure to low frequency noise of high intensity. A determination of the point at which temporary threshold shift rises to its maximum might be a useful starting point for a hearing conservation program, a program clearly indicated for the general flying population.

With the increased noise exposure man is now encountering, it is imperative that an intensified effort be made to protect his hearing. This study has shown that a large population may be exposed to damaging noise and that further research is warranted.

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